
Evaluation of Next Generation Military Vehicle Cooling Systems

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Outline

Unclassified

-
- Thermal Challenges in a Military Environment
 - Traditional vs. Alternative Approach
 - Thermal Testing
 - Thermal Tool
 - Pilot Project – Applying the Simulation
 - Results
 - Next Steps

Thermal Challenges

Unclassified

Military needs differ from most commercial applications

- Longer service life
- Shorter operational life
- Environmental extremes
- Worldwide operation
- Adverse operating conditions
- Both on- and off-road mission profiles
- Minimal maintenance during combat operation



Thermal Challenges

Unclassified

Cooling System Design Factors

- Severe shock & vibration
- Long term storage
- Challenging longitudinal & lateral slopes
- Corrosive battlefield atmosphere & fording
- Ground-hop capability
- Airside clogging of heat exchangers
- Ambient temperature extremes & high altitudes



Thermal Challenges

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Military vehicles are facing ever increasing challenges of meeting cooling system requirements

- Additional armor
- Power upgrades
- Extremely hot environments
- Heat loads associated with hybrids
- Adverse operating conditions



Traditional Approach

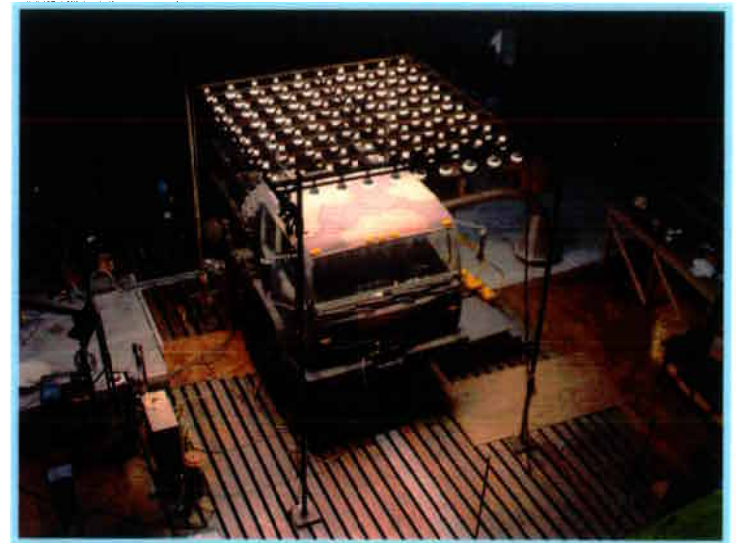
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Meet thermal challenges through thermal testing

- Optimize cooling system performance
- Select improved components – Radiator & Fan
- Conduct vehicle thermal testing
- Evaluate impact to cooling system



6



Alternative Approach

Unclassified

Share thermal challenge through an interactive technique

- Connect vehicle level simulation with vehicle test
- Link 1D simulations to testing process
 - Evaluate multiple vehicle variants/configurations
 - Accomplish rapid optimization of thermal system
 - Identify best candidates to test
 - Achieve thermal goals

Alternative Approach

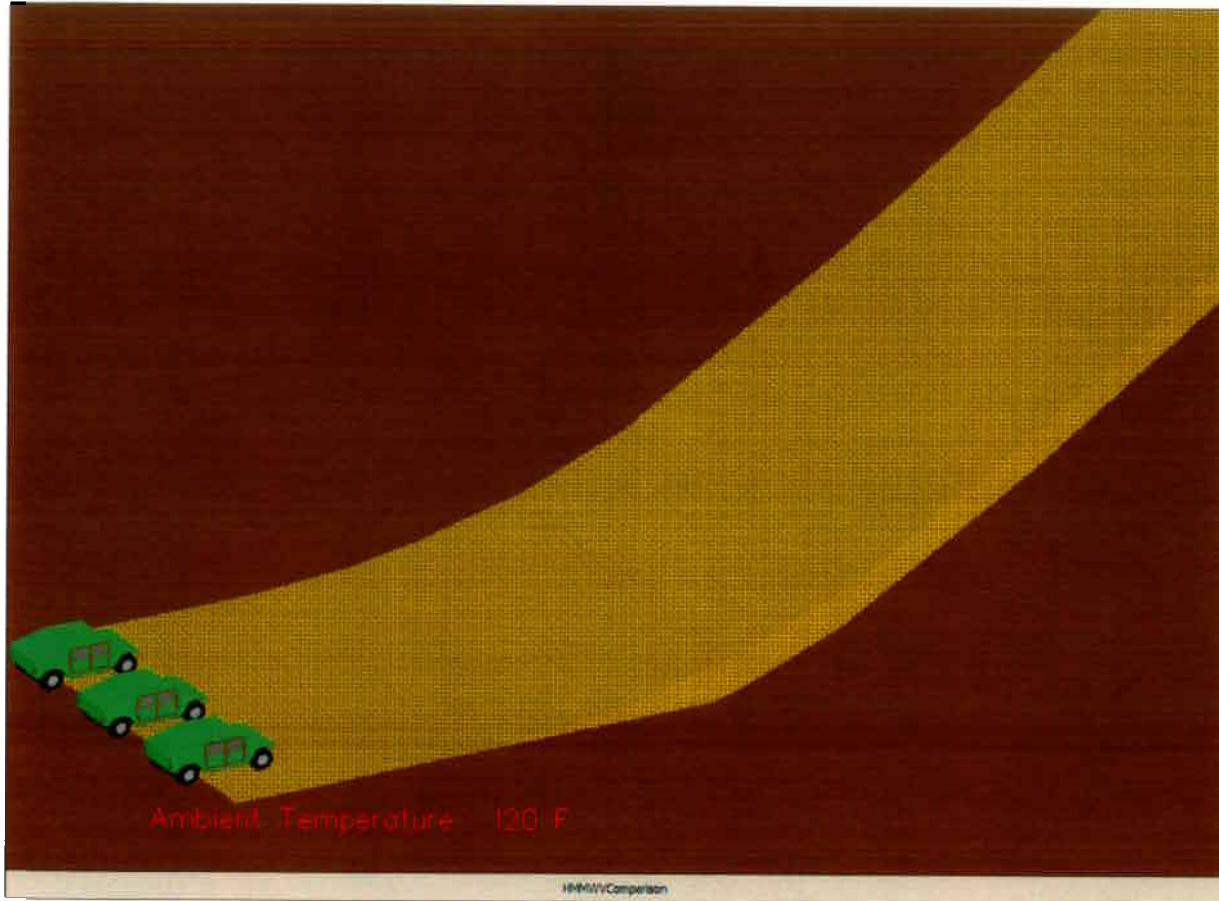
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Benefits:

- Minimize number of tests
- Maximize test results
- Save time
- Reduce cost
- Enhance cooling system performance capabilities

Thermal Testing

Unclassified



Objectives

Maintain critical temperatures within specified limits while operating at:

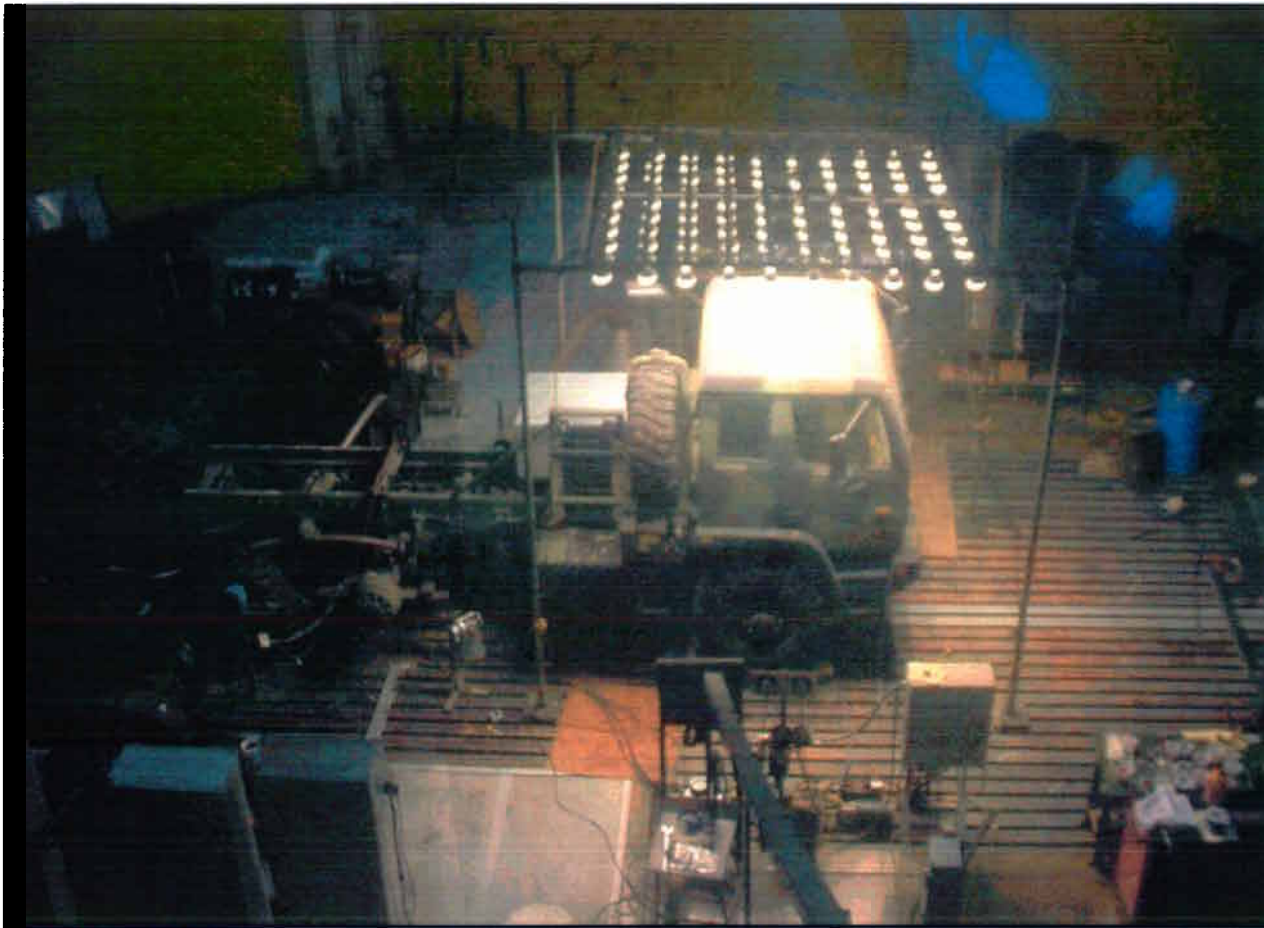
- Full power
- Full load
- Ambient 120°F

Specified Limits

- Engine Coolant 230°F
- Engine Oil 275°F
- Transmission Oil 300°F

Thermal Testing

Unclassified



Test Conditions

- Full Power
- Full Load
- Ambient 120°F
- 5 mph wind velocity
- Solar radiation

Data Captured

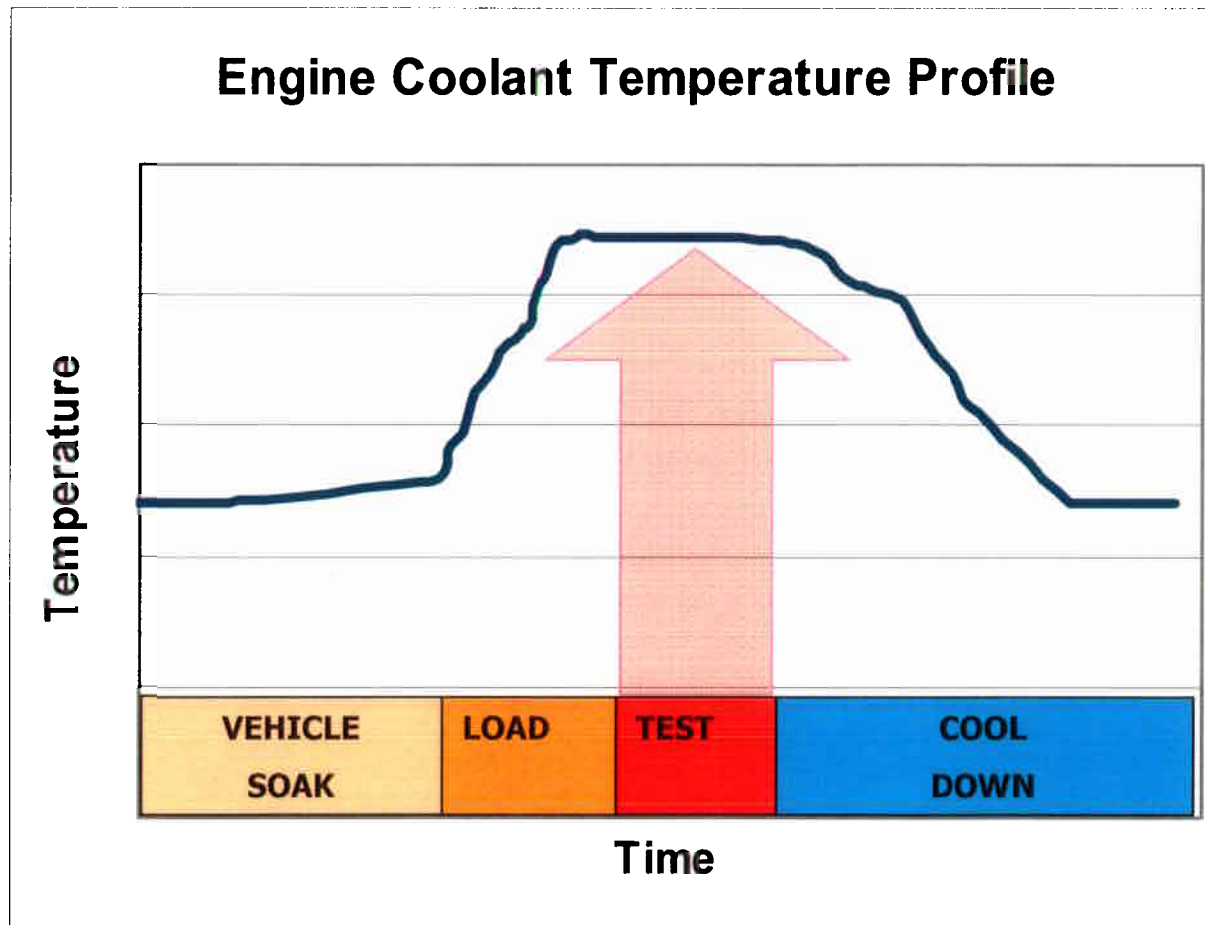
- Engine Coolant
- Engine Oil
- Transmission Oil

Results

Determine if vehicle cooling system meets requirements in various configurations

Thermal Testing

Unclassified



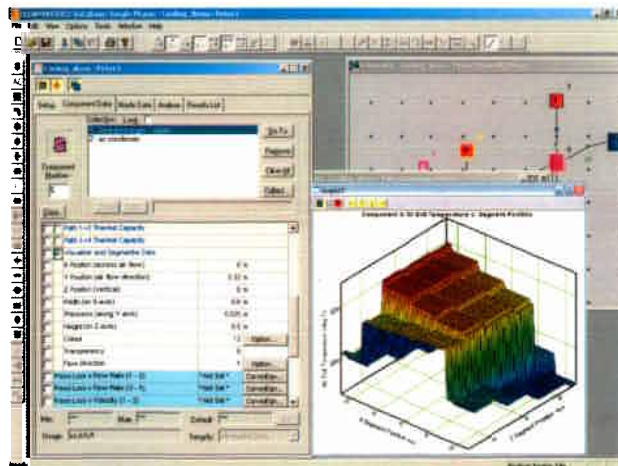
Thermal model simulates steady state conditions during cooling testing

Thermal Tool - Technology

Unclassified

- Highly interactive tool with advanced features focusing on efficiency, accuracy, reliability and usability
- Facilitate connection between simulation and test process

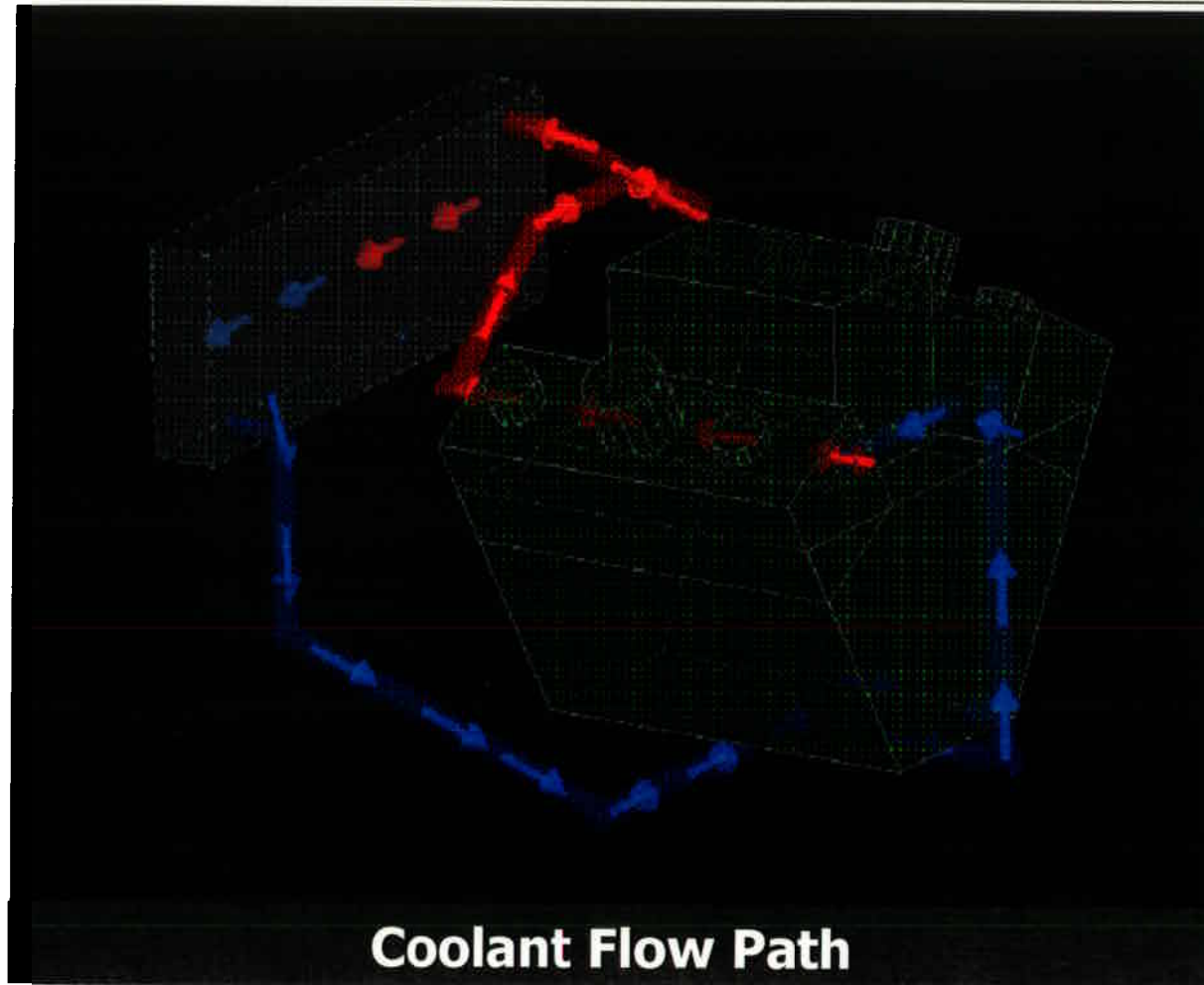
Thermal Tool



Thermal Test

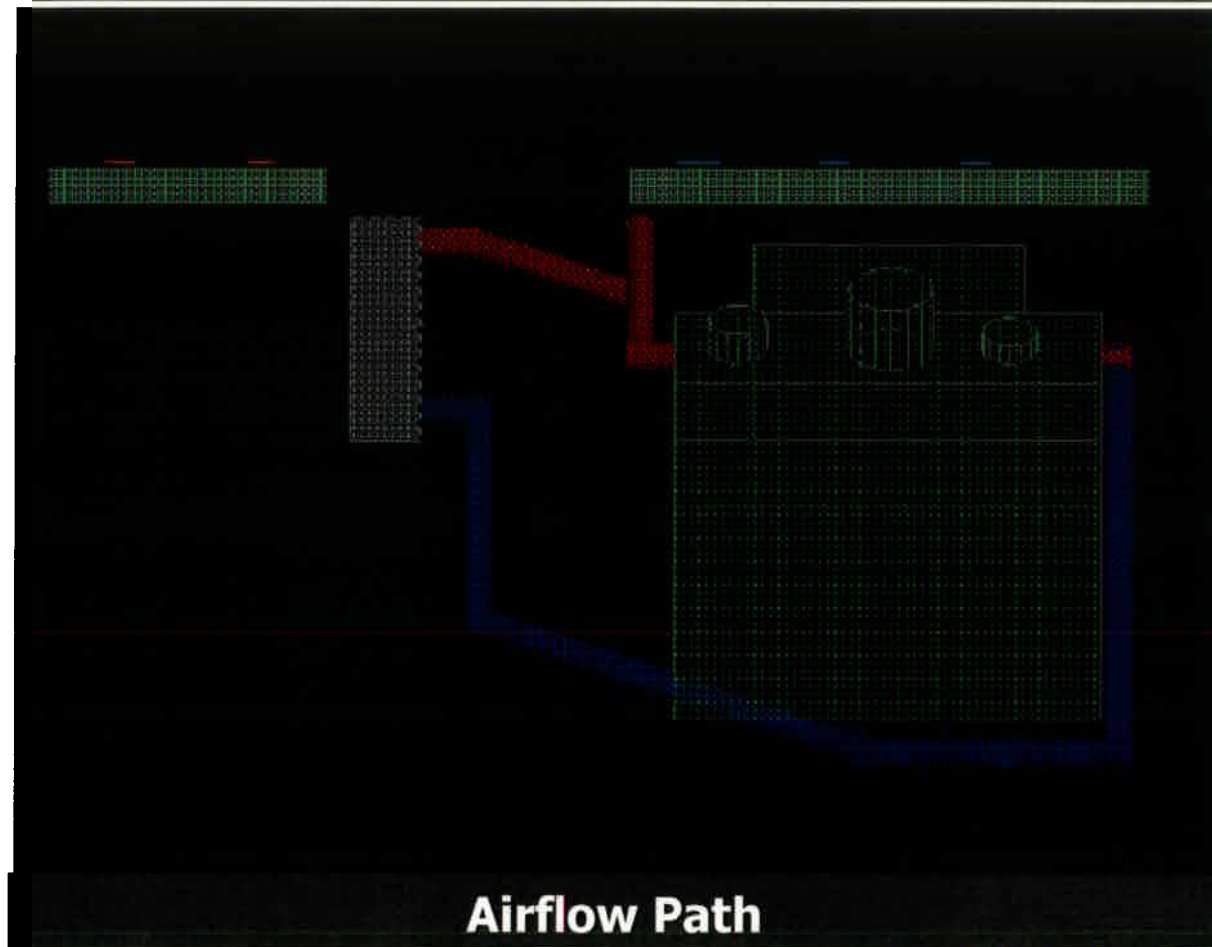


Thermal Tool - Function



- Model the coolant and airflow heat balance
- Predict critical temperatures
- Produce same results as test

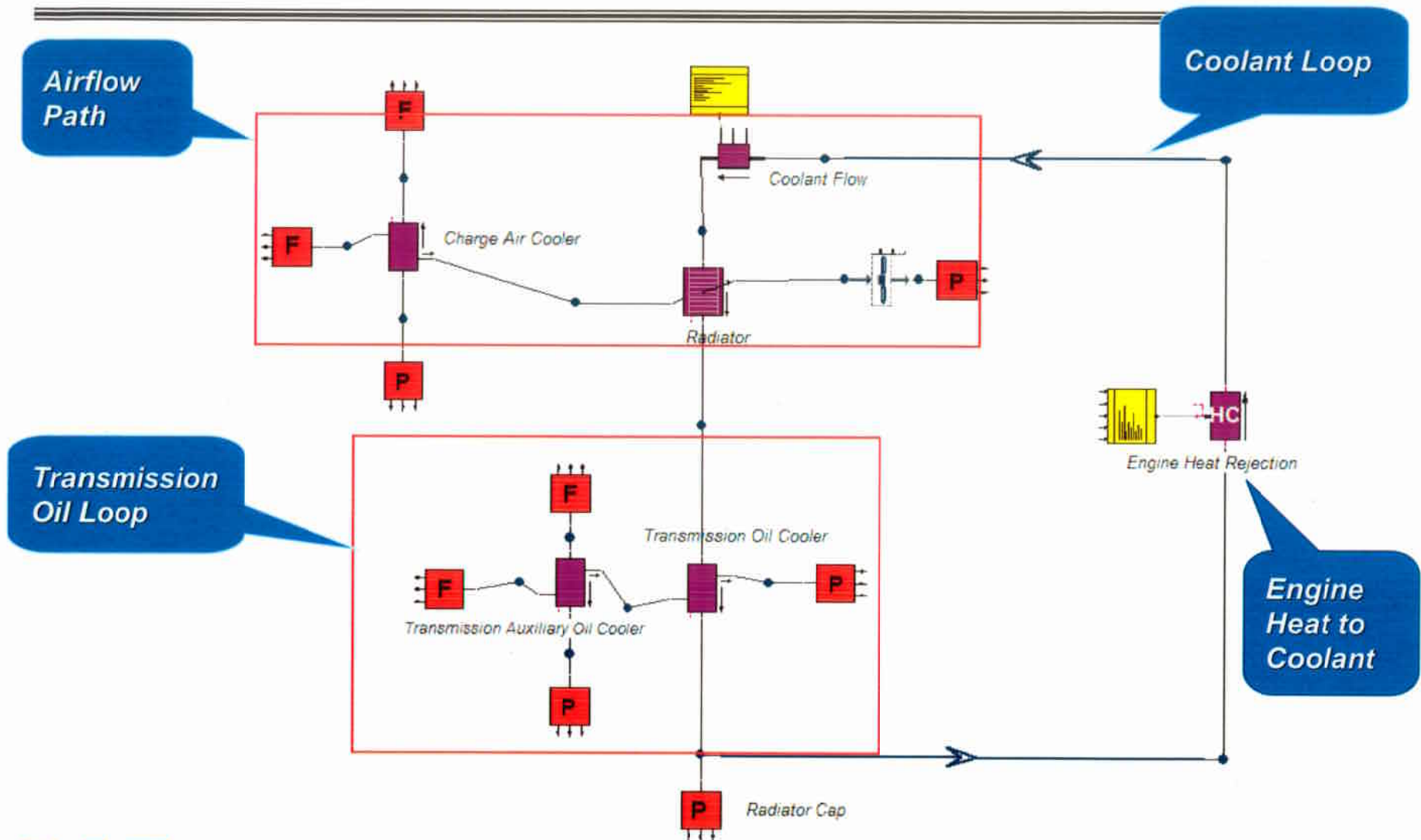
Thermal Tool - Function



- Model the coolant and airflow heat balance
- Predict critical temperatures
- Produce same results as test

Thermal Tool – Function

Unclassified



Pilot Project – Medium Tactical Vehicles

Unclassified



M1087 Expandable Van



M1093 Cargo Truck



M1098 Wrecker



M1090 Dump Truck

Commonality

Differences



Common Chassis

Chassis
Drive Train

Payloads
Mission Requirements



**Material Handling
Equipment**



**Load Handling
System**



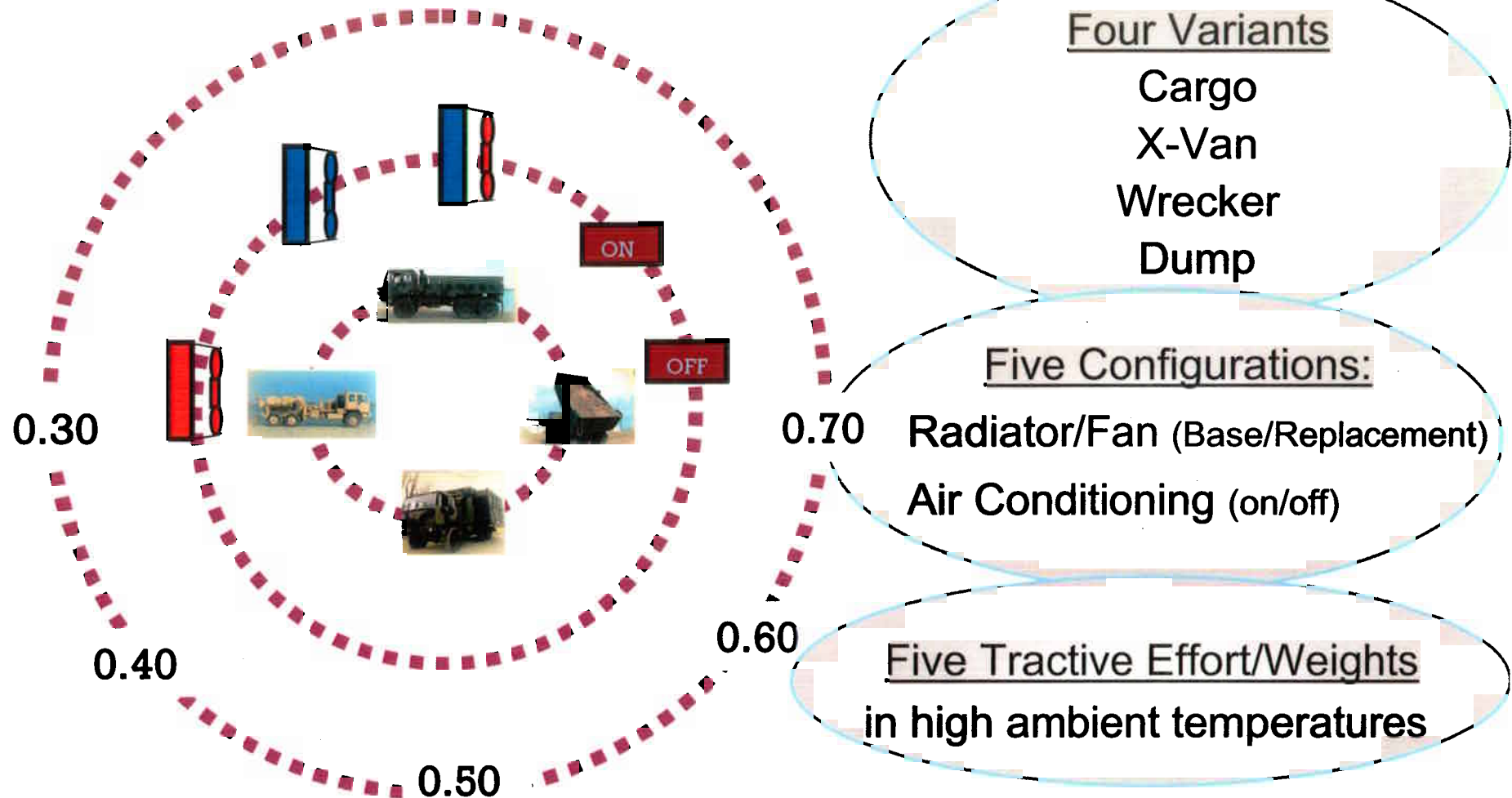
MTV



M1088A1 Tractor

Pilot Project – Test Matrix

Unclassified



Tradition approach only captured 40% of the desired data within this test matrix.

Unclassified

06CV-190

Pilot Project – Work Completed

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Major objectives have been accomplished

- Captured test data from four MTV variants



M1093 Cargo Truck



M1087 Expandable Van



M1098 Wrecker

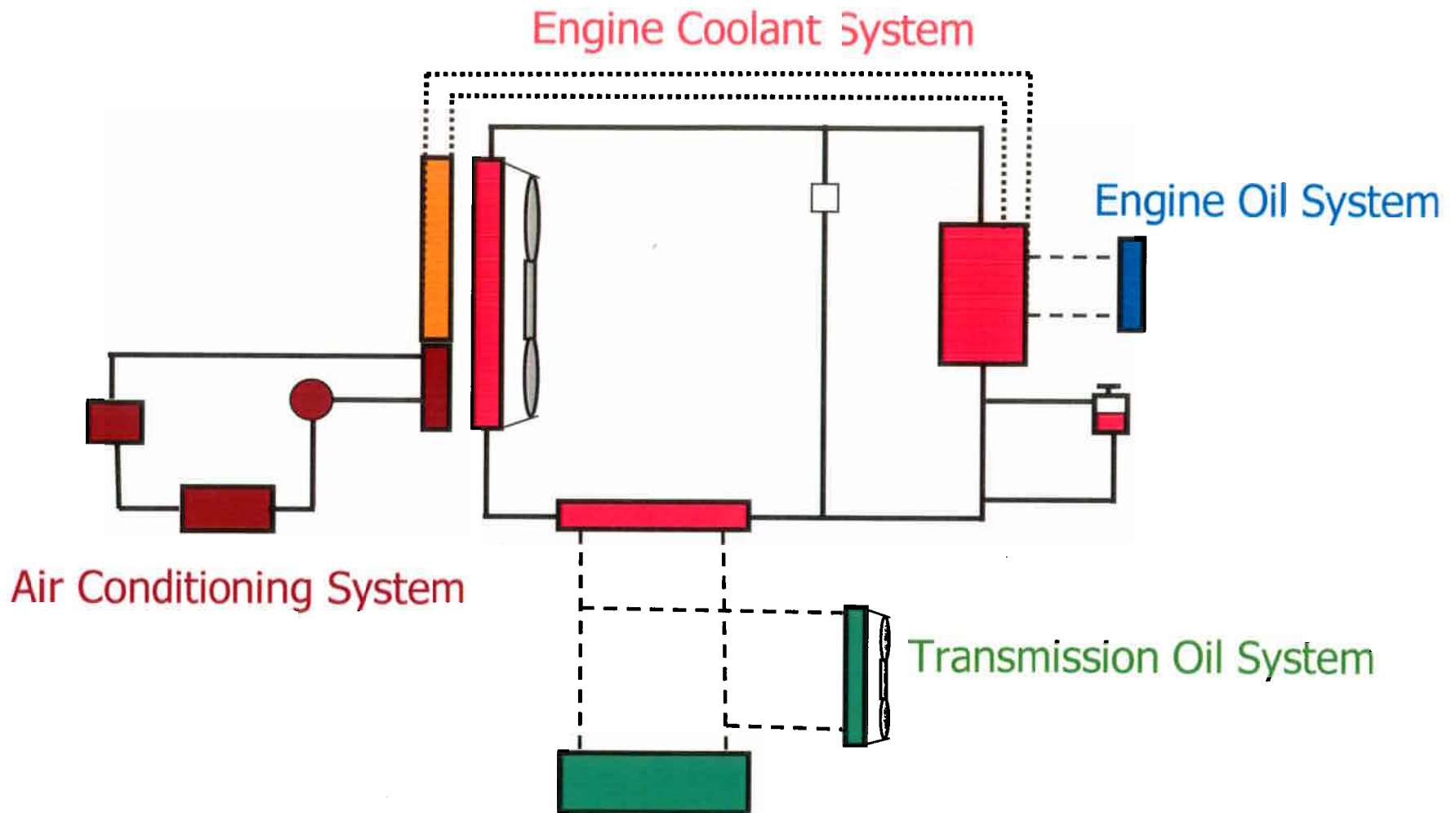


M1090 Dump Truck

- Developed several thermal models
- Validated models using actual test data

Thermal Tool - Thermal Systems

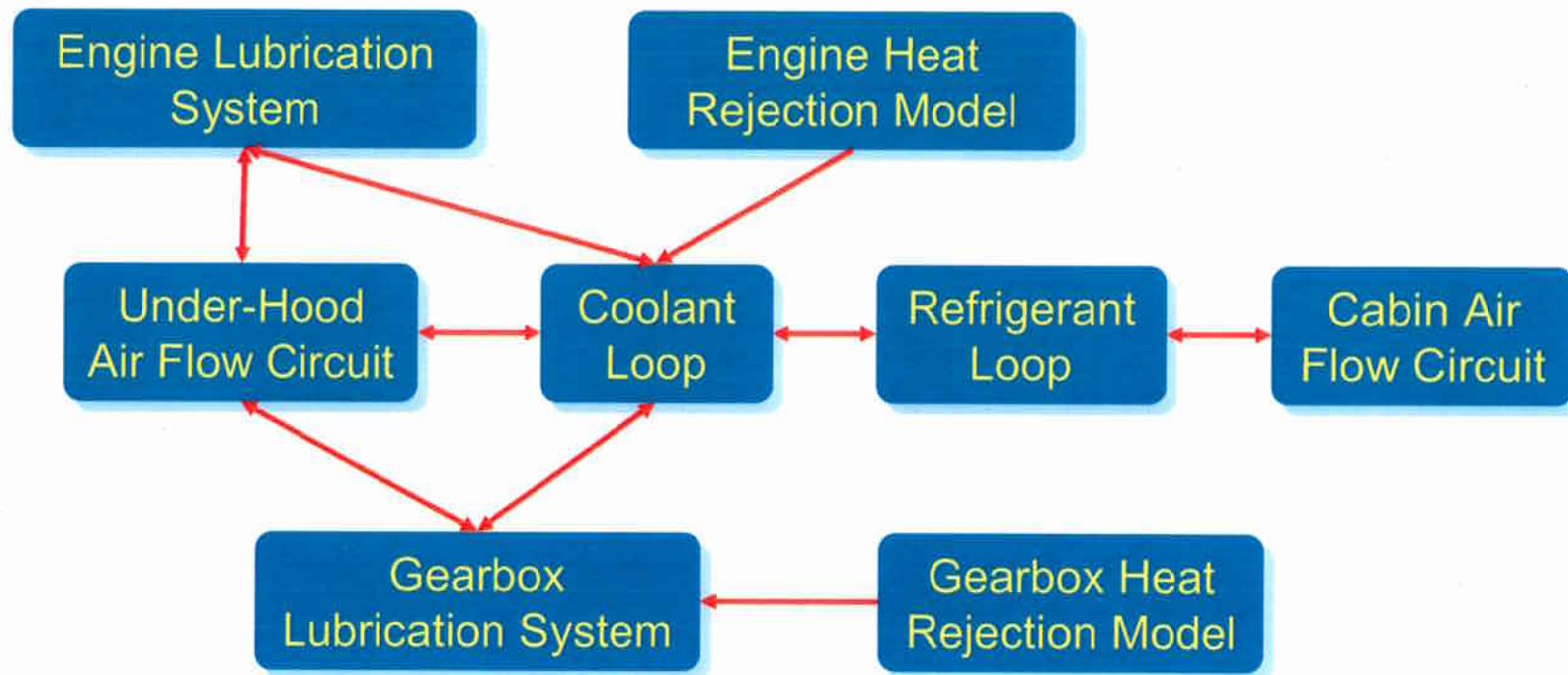
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Thermal Tool - Responsibilities

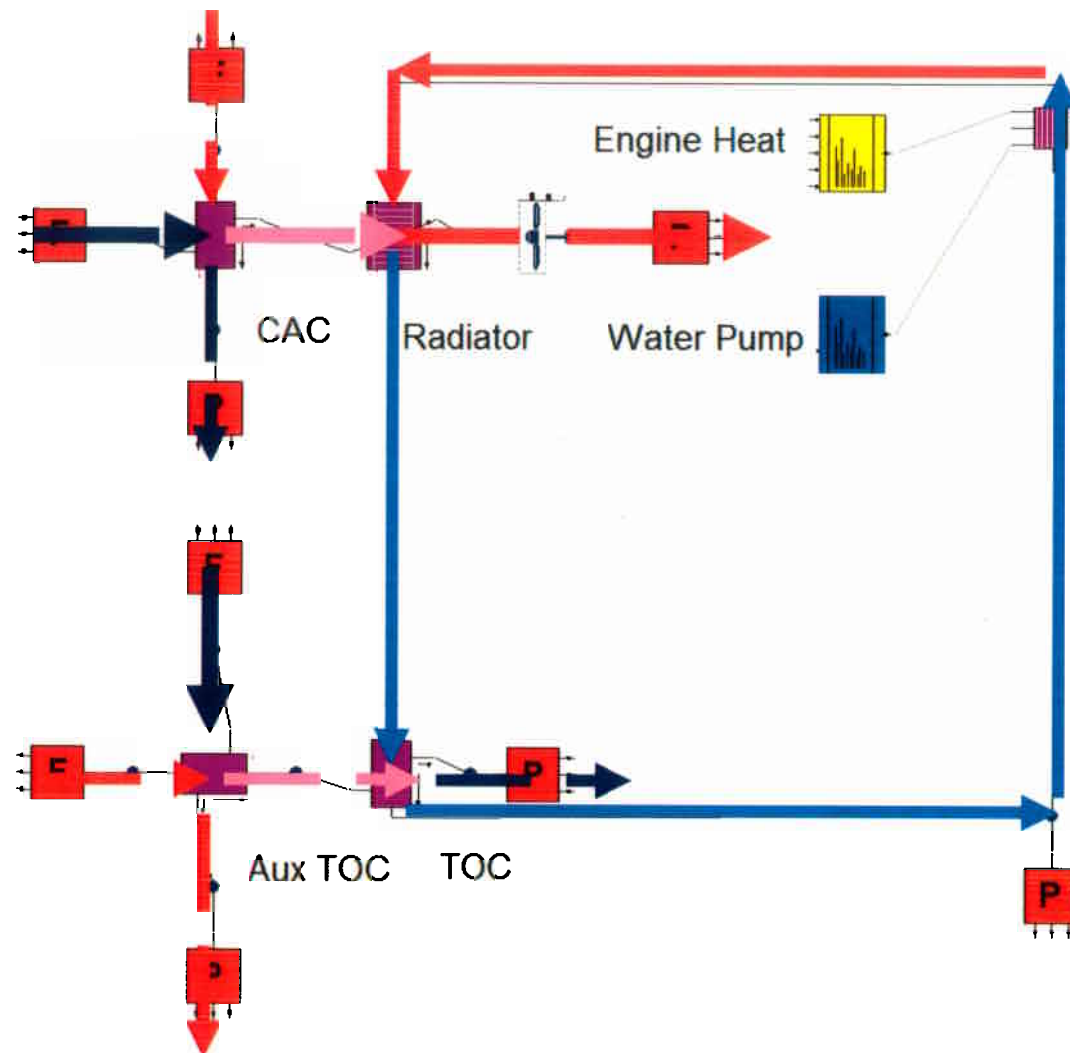
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Thermal system interaction:



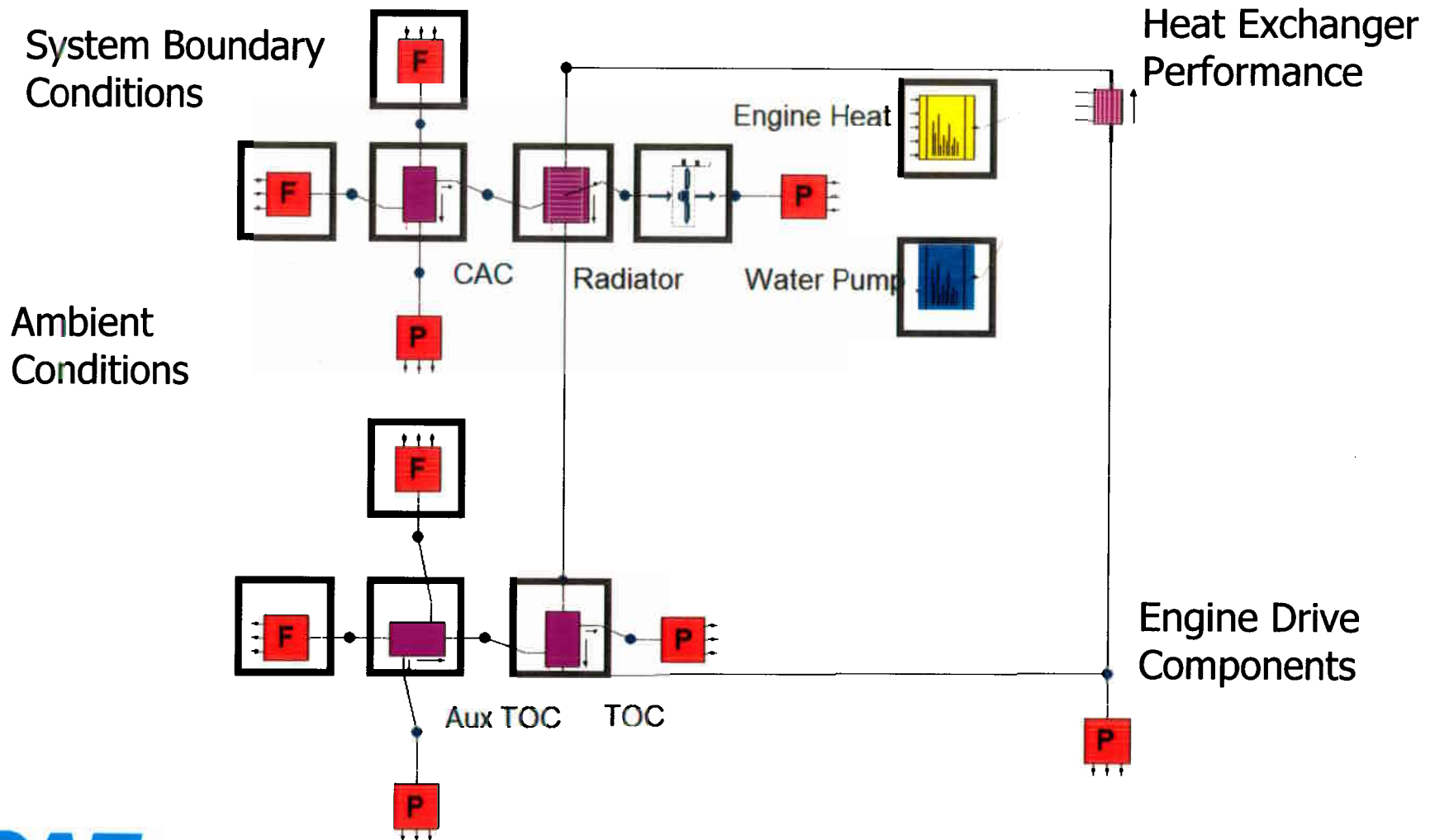
Thermal Tool - 1D Model Set Up

Unclassified



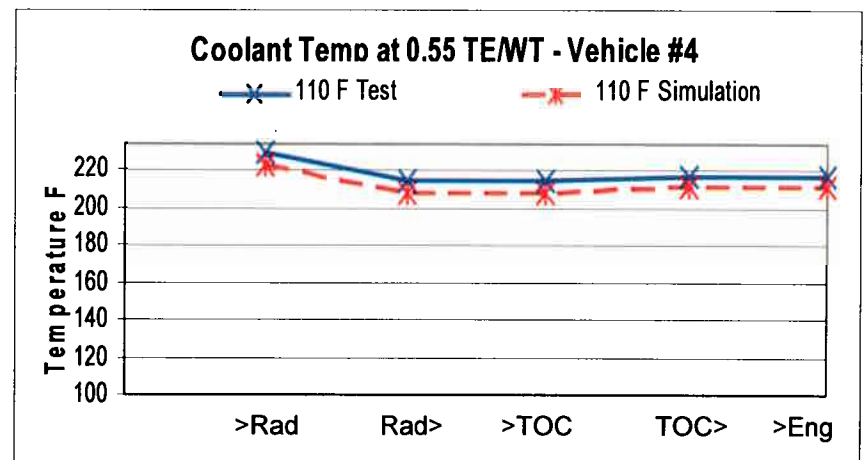
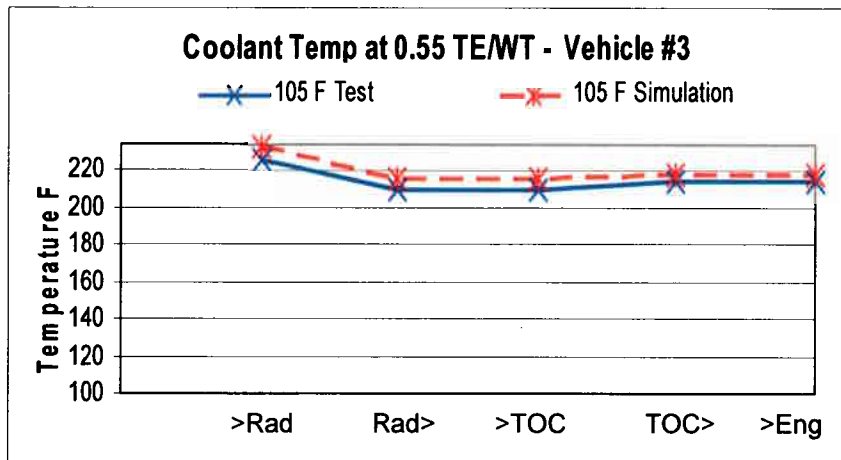
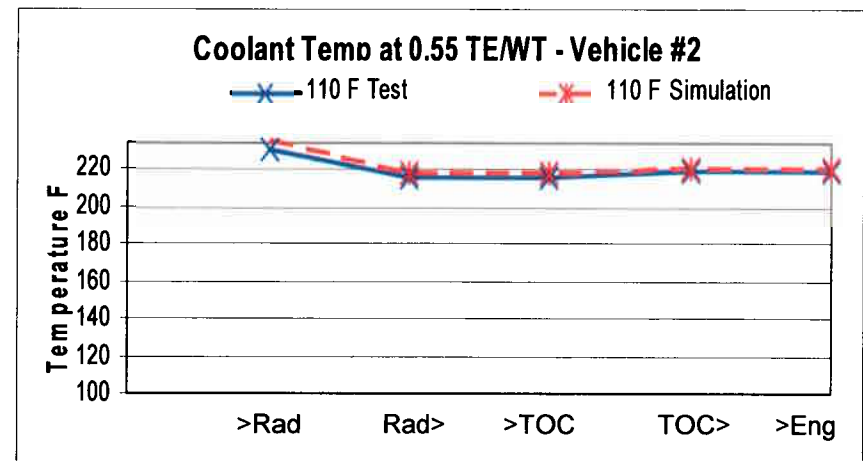
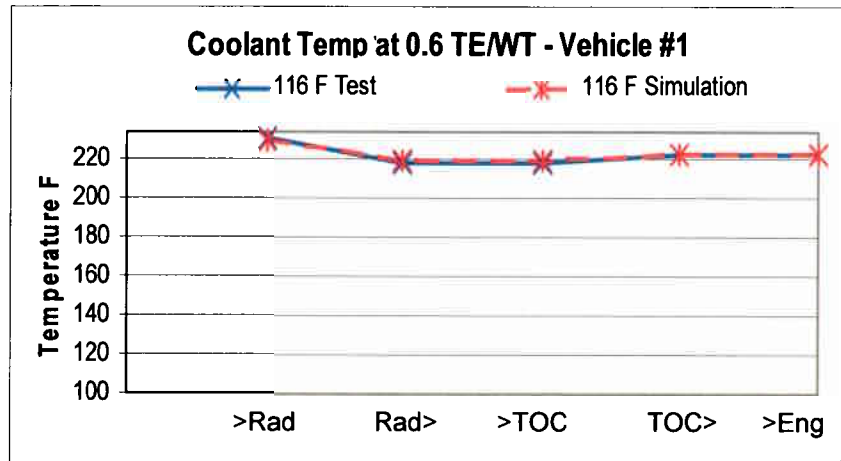
Thermal Tool - 1D Model Set Up

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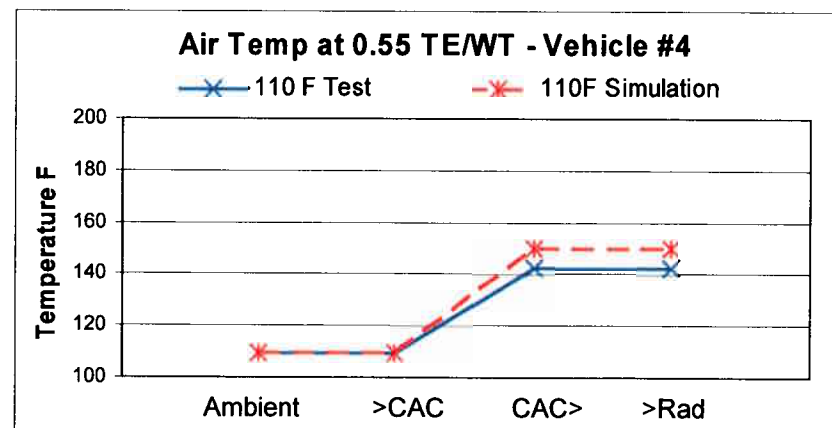
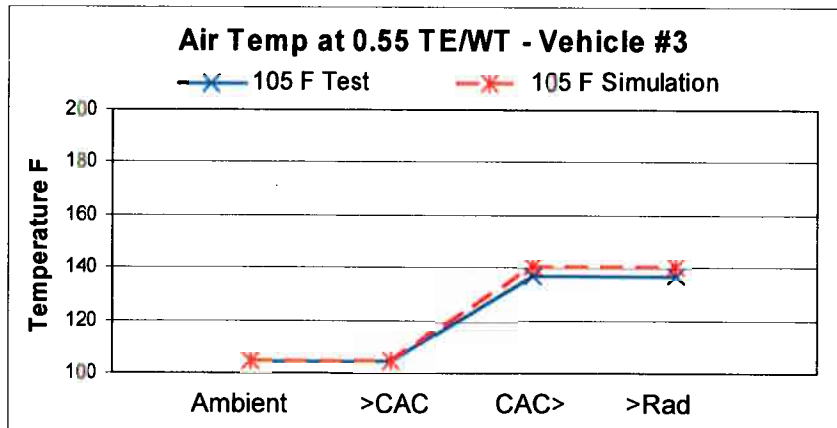
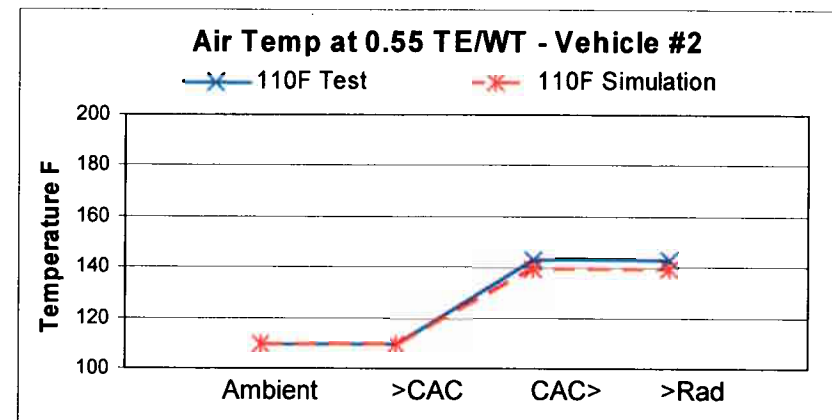
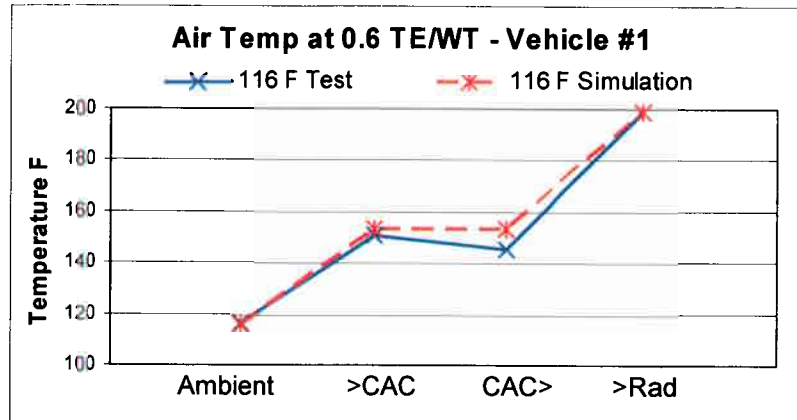
Results – Coolant Temperature

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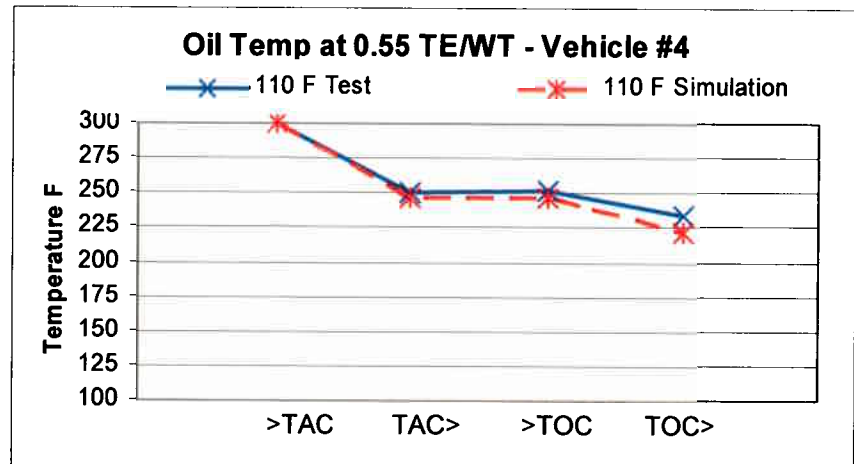
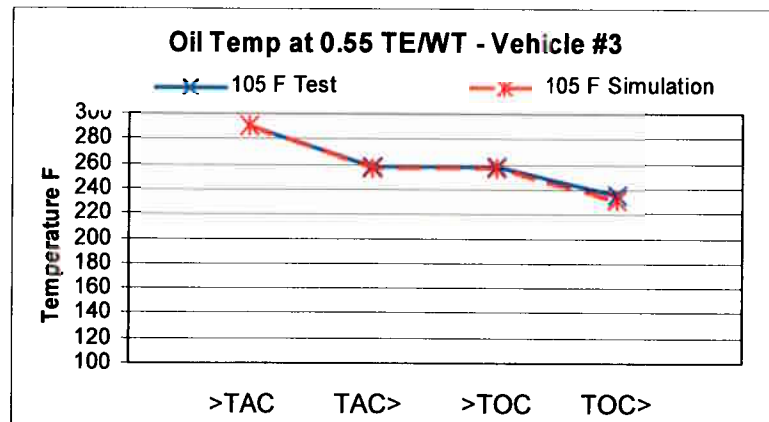
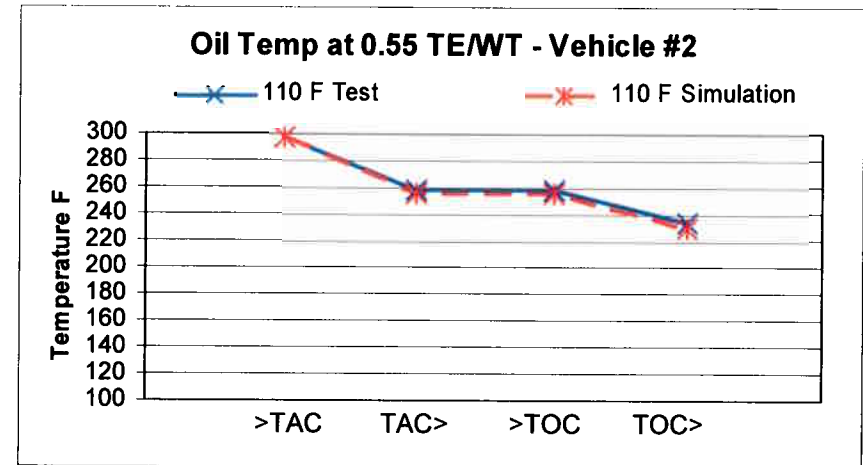
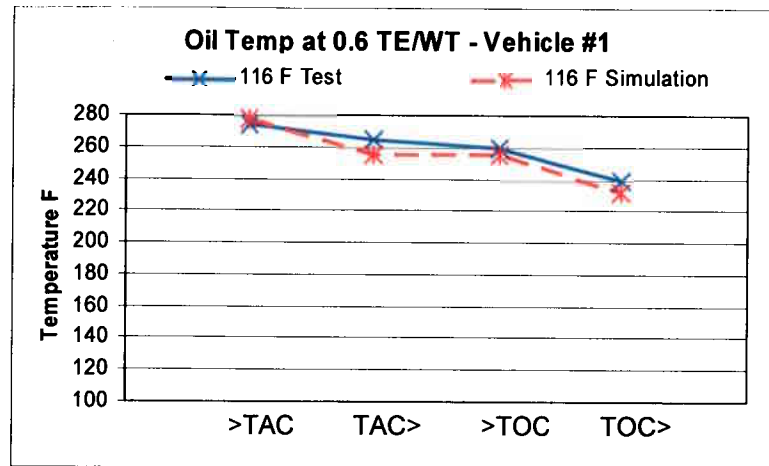
Results – Air Temperature

Unclassified



Results – Transmission Oil Temperature

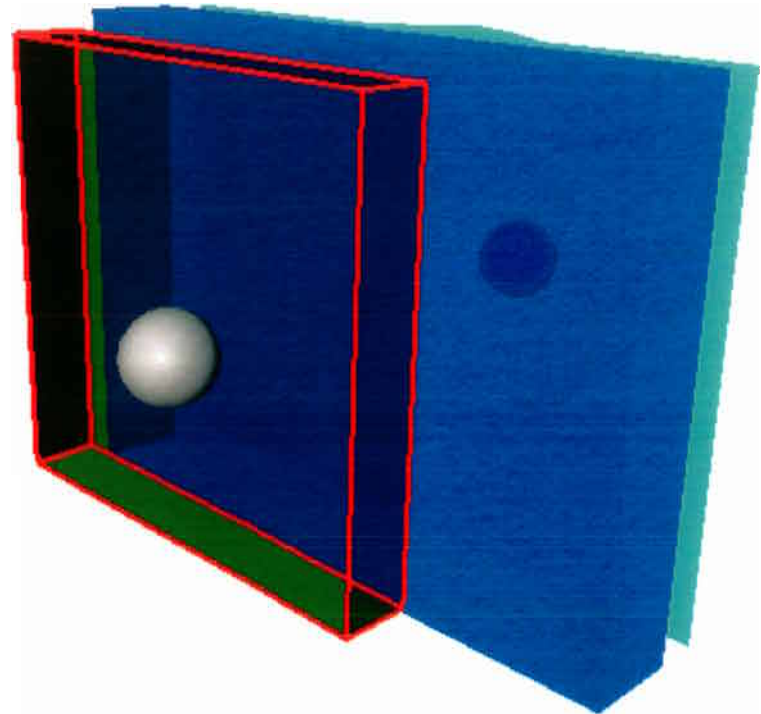
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Next Steps – Additional Variables

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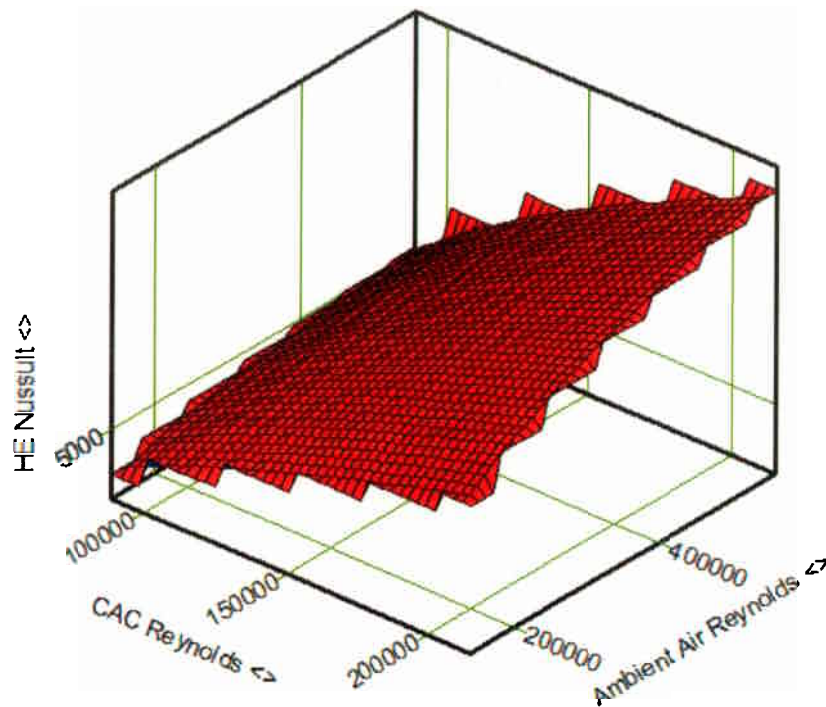
- Performance
 - Equal or better than existing exchanger under same operating conditions
- Variable Geometry
 - Height, width, and depth
- Variable Location



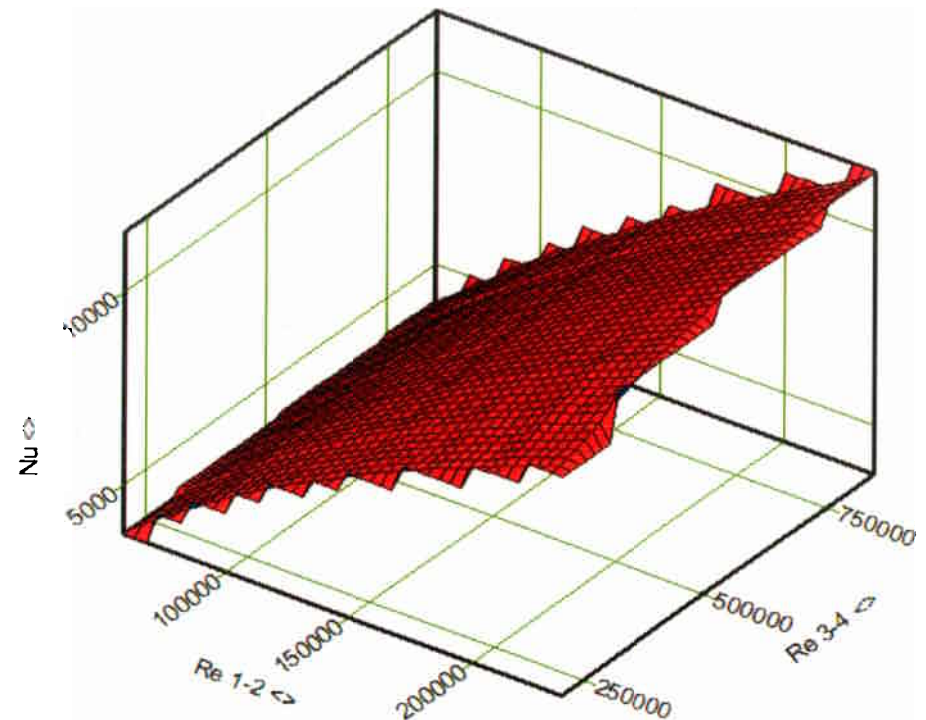
Next Steps - Performance Input

Unclassified

Charge Air Cooler Nusselt Number vs. Re12 vs Re34 V3



CAC Nu v Re1-2 v Re3-4



Next Steps – Automated Approach

Unclassified

Nusselt Number Calculator V5.user.xls

Flowmaster Nusselt Number Calculator

Project and Component Location

Database Folder: C:\Flowmaster_Databases\Flowmaster\Flowmaster_db Pipe Area 1: 1 m²

Project Folder: C:\Flowmaster_Databases\Flowmaster\Flowmaster_ud Pipe Area 2: 1 m²

Project Name: AVE_10205 Width Across Air: 1 m

Network Name: AVE_Example Thickness in Air: 1 m

Surface Title: Run FM Macro Test Vertical Height: 1 m

Heat Exchanger Properties

Thickness (m): 0.001

Hot Side

Fluid Type: G1: 2010 Air 0.020

Flow Area (m²): 1.0E-02

Hydraulic Diameter (m): 0.000825

Inlet Pressure (bar): 1

Air Side

Fluid Type: D1: Air 0.001

Flow Area (m²): 0.333

Hydraulic Diameter (m): 0.001

Inlet Pressure (bar): 1.013

Required Calculation Steps

1. Click to populate dropdown menus with fluids from FLOWMASTER2 database
2. Click to calculate Nusselt number
3. Click to add to Flowmaster
4. Update Network
4. Start Flowmaster

Required Data

1) Enter Database Dir. and Project Dir.
2) Enter Project Name and Title
3) Enter 'Measured Data'
4) Click button 1 to read database fluid/
5) Select required fluids from dropdown menus
6) Click button 2 to calculate Nusselt Number
7) Enter in 'Surface Title'
8) Click button 3 to add your surface to FM
9) Click button 4 to run FM analysis and view results

Results

Temperature (°C) Heat Duty (kW)

Note:
Highlighted cells in this column indicate values that have been limited to prevent errors.

Required Data		Optional Data (give T or Duty)		Data Retrieved from FLOWMASTER2						Calculated Results										
Mass Flow Rate (kg/s)		T _{in} (°C)		T _{out} (°C)		Heat Duty (W)	Hot Side			Air Side			ΔT _i	m _{air} (kg/s)	m _{water} (kg/s)	q (W/m²)	U (W/m² K)	Re _{air}	Re _{water}	Nu
Hot Side	Air Side	Hot Side	Air Side	Hot Side	Air Side		Specific Heat (J/kg K)	ρ (N/m³)	Specific Heat (J/kg K)	Thermal Cond. (W/m K)	Viscosity (N s/m²)									
0.328833333	0.8071004	80.8	25.4	58.57871	58.84033	2485.648	3554.88094	0.001206	1010.039763	0.027384644	1.81E-05	51.4	1163	815.222	0.4129994	3553.194	454.8111	126.25494	2076.0198	
1.619160667	0.806242	80.8	27.3	70.123978	67.758308	32952.064	3565.505626	0.001367	1010.283968	0.027505045	1.84E-05	53.5	5005.62	814.533	0.1060947	3950.6894	2636.7653	125.3032	2291.6628	
0.496	0.8065906	80.9	29	67.30551	65.04129	30392.572	3572.36012	0.001074	1010.226484	0.027579523	1.84E-05	51.5	2143.47	824.959	0.2498851	4227.1854	1000.0925	125.92409	2452.2617	
0.578666667	0.8052338	81.5	29.8	72.557378	68.11189	31350.352	3582.872926	0.001852	1010.24888	0.027680936	1.84E-05	51.7	3505.66	817.66	0.1276747	406.0685	855.9475	125.34723	2401.7488	
0.328833333	1.391111	80.7	30.4	83.067291	82.258887	32114.024	3580.120078	0.001398	1009.920959	0.02781868	1.81E-05	50.3	161.75	1404.93	0.5495576	4568.7901	411.8881	219.0874	2688.895	
0.3275	1.9819366	80.9	30.1	49.80532	48.07586	35975.58	3532.702244	0.001406	1009.819327	0.0270629	1.80E-05	50.9	155.36	2001.4	0.6121047	4791.177	392.05681	314.2815	2640.3002	
1.955666667	0.7708469	80.4	27.3	75.679524	70.262325	32415.2	3589.803204	0.001051	1010.36778	0.027666339	1.84E-05	53.1	702.65	778.954	0.0597262	4407.721	789.5969	119.47813	2548.0738	
1.2335	0.8045455	81.4	30.6	74.424703	70.3996	32346.76	3585.294365	0.001367	1010.461325	0.027738825	1.85E-05	50.8	4837.57	812.962	0.1173105	4537.863	2102.3381	124.8886	2512.4127	
0.656333333	1.3417882	81.3	28.3	83.88862	57.48533	40735.652	3564.80476	0.001545	1009.571201	0.027259348	1.82E-05	53	2338.77	1395.57	0.3284931	4641.801	959.78362	217.0534	2724.5265	
0.9705	1.3679433	81.9	28.5	88.282905	58.959572	44019.772	3576.578866	0.001857	1010.016307	0.027741776	1.82E-05	53.8	3488.95	1381.64	0.2345096	4686.51	816.3122	214.26768	2742.4757	
0.328833333	3.16297245	82.7	31.7	47.533093	44.455106	40738.619	3529.801542	0.001522	1009.778793	0.026869557	1.8E-05	51	156.42	3193.81	0.6895583	5324.2238	3814.8082	502.7025	3855.9999	
0.6955	1.98366702	81.7	28.5	61.16202	52.382371	47602.363	3595.953127	0.001894	1009.873318	0.02708464	1.81E-05	53.2	2333.55	2003.25	0.3850532	5054.1246	930.42723	313.4632	2986.1377	
0.328833333	4	80	30	42.008433	40.86241	42970	3511.534417	0.0016291	1009.674641	0.02677394	1.80E-05	50	1154.71	4638.7	0.7588447	6389.5434	340.77213	639.87807	2626.4475	
1.293333333	1.39406345	81.4	28.9	71.061732	63.883633	47857.436	3579.147017	0.001705	1010.17102	0.027545504	1.84E-05	51.5	4529.03	1408.25	0.2667484	5671.942	2039.7257	256.9127	3294.5875	
1.294333333	1.91660136	80.8	27.9	68.11028	56.525413	57721.088	3572.958034	0.001937	1009.544303	0.027208629	1.81E-05	52.9	4624.6	2016.46	0.225945	5846.2269	873.8456	314.14443	3437.7208	
0.975833333	1.95521411	82.4	31.9	67.05795	58.946256	53492.877	3573.039526	0.001705	1010.072443	0.027444403	1.83E-05	50.5	3488.65	1974.31	0.3038023	6090.8063	1487.5121	305.2418	3545.8908	
1.6216	1.93182342	80.5	27.5	70.20810	57.373468	56880.373	3578.892082	0.001854	1009.948031	0.027288624	1.82E-05	53	5789.83	2012.24	0.194191	5935.6704	252.210	313.22561	3477.3902	
0.657833333	2.21064891	81.9	31.4	57.017706	48.888033	56745.85	3552.450491	0.002453	1009.86166	0.027059713	1.80E-05	50.5	2336.92	3244.32	0.488388	6259.6702	891.80493	508.0285	3701.2485	

Master Copy

Next Steps - Results

Unclassified

Top Tank Temperatures

	Vehicle A	Vehicle B	Vehicle C
Heat Exchangers			
X	180 °F	200 °F	210 °F
Y	180 °F	200 °F	210 °F
Z	180 °F	200 °F	210 °F

Next Steps - Observations

Unclassified

- Simulation accurately represents cooling system performance
- Thermal simulation simplified complex interactions
- Initial validation process utilized:
 - Pre-processed component test data
 - Comprehensive vehicle test data
- Process enables rapid and accurate analysis
 - Heat exchanger options
 - Multiple vehicle variants
- Validating process for future heat exchanger evaluation

Thanks for attending!

Questions?

Mary Goryca, US Army Tank Automotive Research,
Development and Engineering Center

Neil Slyva, Flowmaster USA

